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Natural Resource Stewardship and Science

Water Resources of Wind Cave National Park

Natural Resource Report NPS/WICA/NRR—2016/1247

ON THIS PAGE
Photograph of Boland Ridge Spring in Wind Cave National Park.
Photograph courtesy of the National Park Service (Marc Ohms)

ON THE COVER
Photograph of Calcite Lake within Wind Cave. A thin layer of calcite floats on the lake surface.
Photograph courtesy of the National Park Service (Dan Austin)

Water Resources of Wind Cave National Park

Natural Resource Report NPS/WICA/NRR—2016/1247

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U.S. Department of the Interior
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Fort Collins, Colorado

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Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.
This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Abstract

This report describes the water resources of Wind Cave National Park and summarizes past and ongoing hydrological studies. The Park's water resources are vital for the vegetation, wildlife, cave resources, park visitors, and employees. In fact, without water to carve the region's cave networks, the Park itself would not exist. The National Park Service (NPS) Management Policies of 2006 mandate that the Park protect its surface and ground water resources[1]. The Foundation Statement for the Park (2011) identifies five fundamental resources, which are defined as those resources critical to achieving the Park's purpose and maintaining its significance. The cave, karst, and water resources are on the list. The analysis of fundamental resources articulates the importance of each fundamental resource and value, the resource's current condition, potential threats, and the related issues that need consideration in planning for and management of the resources. Identifying the resources and values that support the park purpose and significance provides managers with a focus on what is truly most important about a park. If the fundamental resources are degraded, then what is most important about the Park may be jeopardized.

The objectives of this report are to 1) provide an inventory of the water resources of Wind Cave, 2) document both past and ongoing water resource investigations, and 3) identify impacts to Park water resources. Ultimately this report is designed to be a tool to help park management make informed decisions to help protect its surface and groundwater resources.

[1] See sections 4.6 (Water Resource Management) and 4.8.1.2 (Karst)

Introduction

Wind Cave National Park is located in western South Dakota, on the southern edge of the Black Hills. The park is located seven miles north of Hot Springs, South Dakota and is bounded by Custer State Park on the north, Black Hills National Forest on the west, and private property on the south and east (Figure 1).

The 10,532 acre park was established in January 1903. Wind Cave was the eighth national park and the first created to protect a cave. The original legislation applied only to the cave and surface developments needed to manage and care for the cave.

The purpose of Wind Cave National Park has evolved from cave preservation to protection of both subsurface and surface ecosystems. In 1912, establishment of the Wind Cave Game Preserve provided a permanent range for bison and “such other native American game animals as may be placed therein.” Herds of bison and elk were re-established as the need to preserve and protect big game species was realized. In 1935, management of the game preserve was transferred from the Department of Agriculture, to Wind Cave National Park. Through a series of expansions, by 2016, the park encompassed 33,891 acres.

The gently rolling landscape of the park is a transition zone between plains and mountains, and supports a great diversity of plant and animal species. The park's mixed-grass prairie is one of the few remaining and is home to native wildlife such as bison, elk, pronghorn, mule deer, coyotes, prairie dogs, and black-footed ferrets.

The cultural resources of the Park include archeological evidence of Plains Indian cultures, European settlement, and ranching. Properties listed on the National Register of Historic Places are associated with early cave exploration and tourism, and Civilian Conservation Corps.

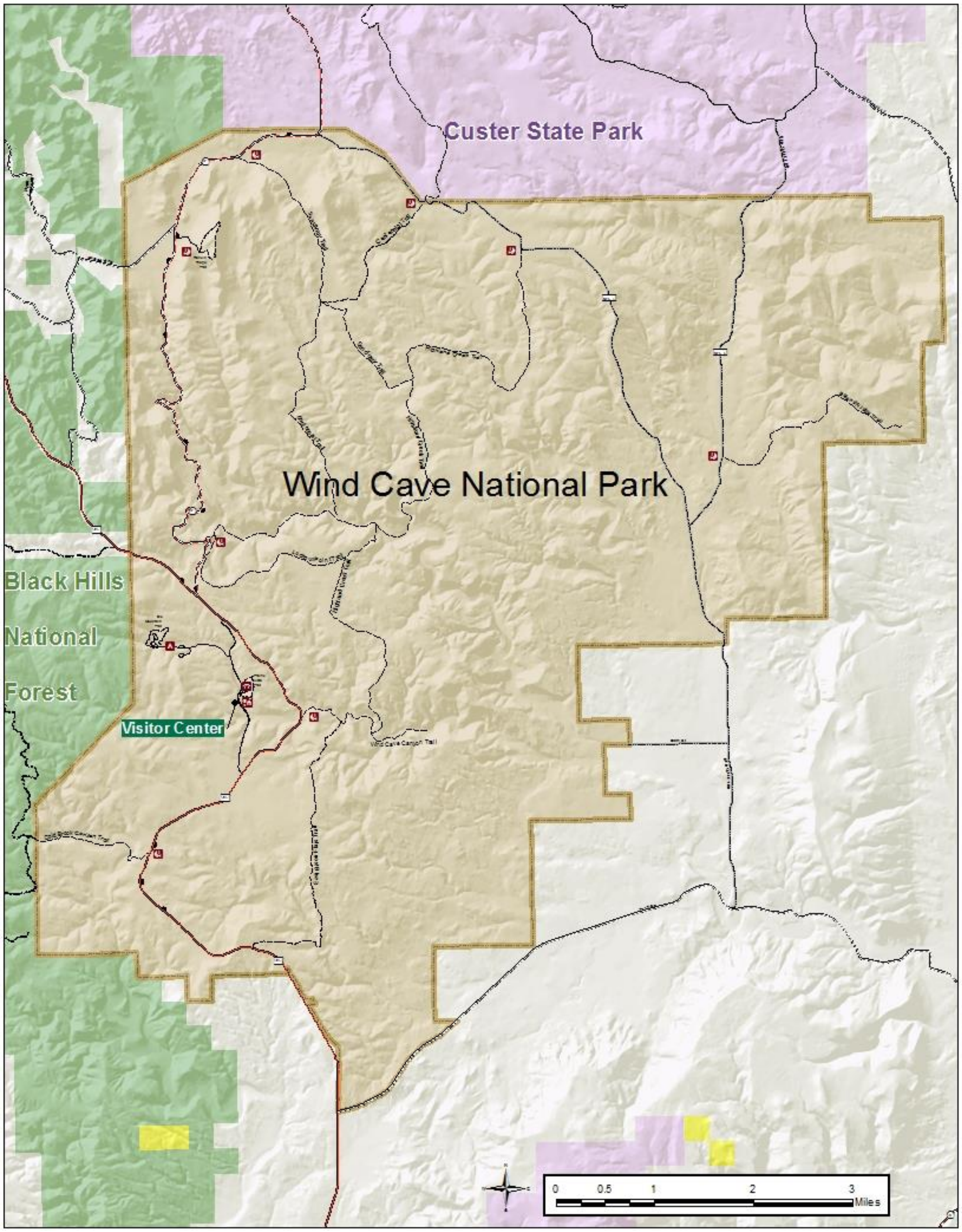

Figure 1. Map of Wind Cave National Park (*NPS*)

Precipitation

A discussion of the water resources of the Park starts with precipitation, since all water within the park, regardless of location or form, begins as precipitation. The Park has maintained a National Weather Service station since 1952 and kept continuous records of precipitation and temperature (Figure 2.) Since 1952 the park has averaged 18.34 inches of precipitation annually. The highest annual precipitation was in 1998 with 28.87 inches, and the lowest on record was 10.02 inches in 1960. The late spring and early summer period typically brings the bulk of the precipitation, with May being the wettest month. Carter et al. (*2002*) estimated that in the Black Hills 91.6 percent of the precipitation is returned to the atmosphere via evapotranspiration, 3.5 percent recharges groundwater, and 4.9 percent is runoff. Assuming that this distribution applies to the Park, from an average of 18.34 inches of precipitation a year, 16.79 inches is evaporated and transpired via vegetation, 0.90 inches is runoff, and 0.64 inches recharges the aquifers. Of course, these values over-simplify actual conditions, but they provide a general idea of the water budget in the Park.

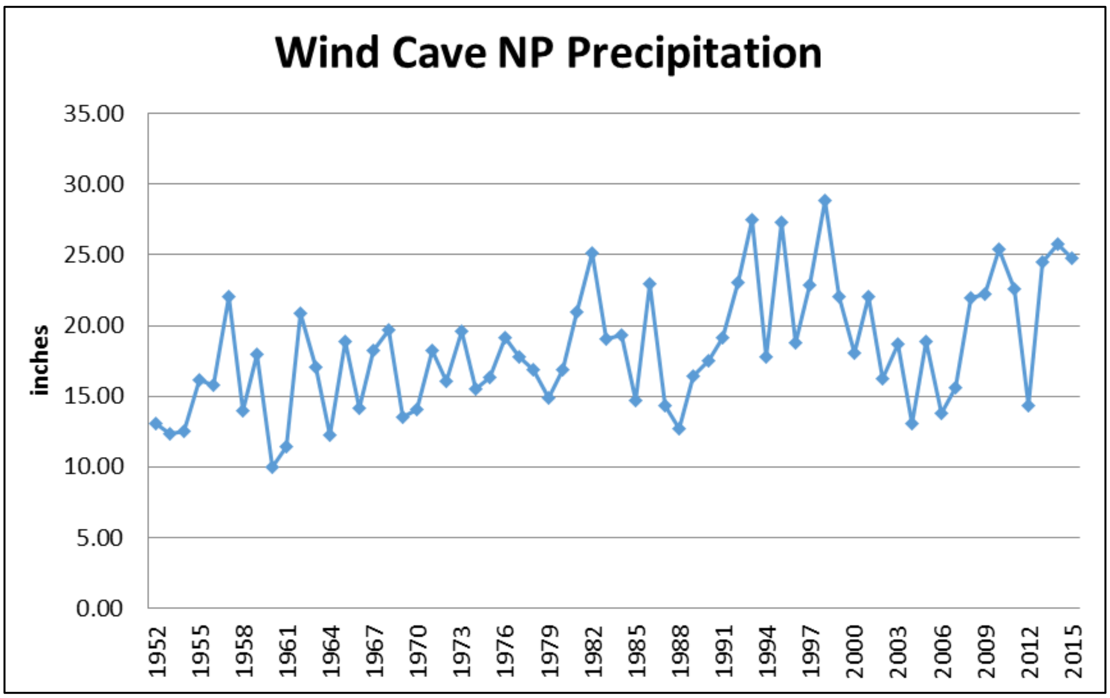

Figure 2. Annual precipitation (*NPS 1952-2015*)

In November of 2002 a National Atmospheric Deposition Program (NADP) air quality monitoring station was installed at the Park and funded by the NPS Air Resource Division. The purpose of the NADP equipment is to collect data on the chemistry of precipitation for monitoring of geographical and temporal long-term trends. The precipitation at this station is collected weekly and is provided to the Central Analytical Laboratory where it is analyzed for hydrogen, pH, sulfate, nitrate, ammonium, chloride, and base cations (calcium, magnesium, potassium and sodium.) Although it is primarily an air quality monitoring program, the data provides useful information on the quality of the water from precipitation entering the Park (Figure 3).

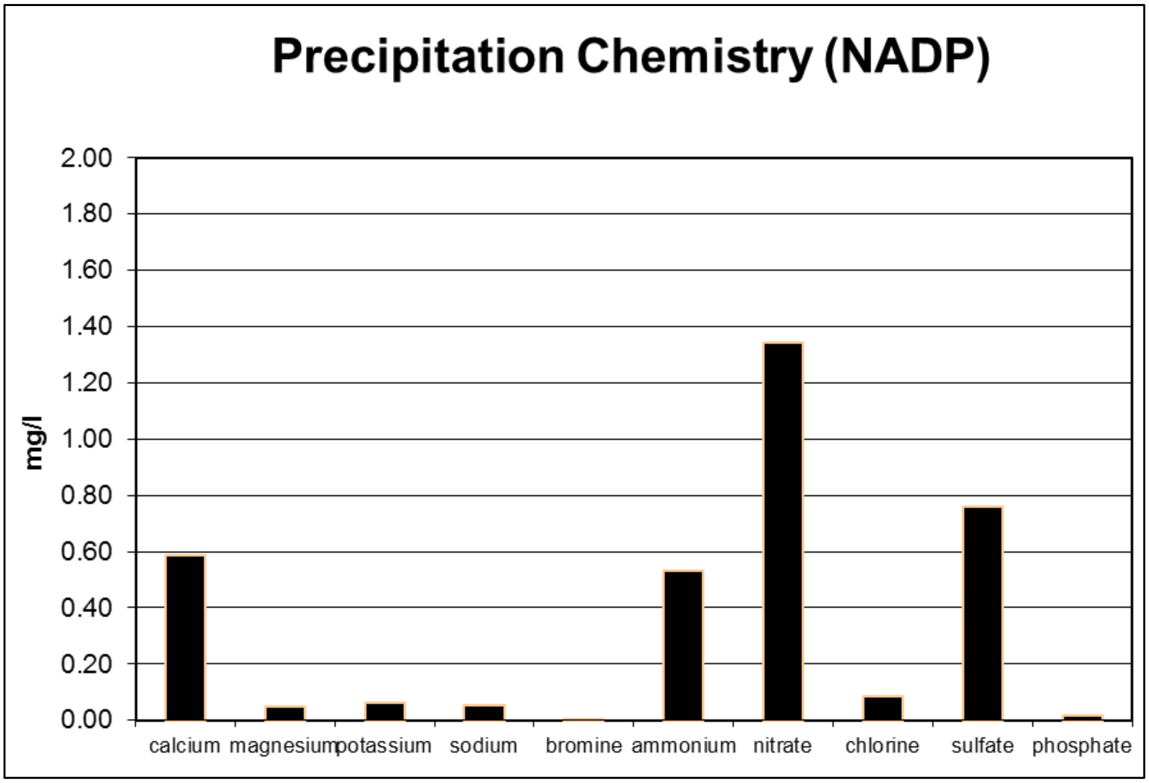

Figure 3. Average Precipitation Chemistry (*NADP 2002-2015*)

Precipitation from 251 NADP sites within Canada and the United States were used to monitor fission-product isotope fallout after the March 2011 Fukushima Nuclear Power Plant incident. Fission products were detected in precipitation samples from 35 individual NADP sites, including the Park. Both Cesium-137 and Cesium-134 were detected. Cesium-137 has a half-life of 30 years, so it will be present in the environment for some time. Wetherbee et al. (*2012*) concluded that cesium levels at the Park are very low and pose no immediate danger. The current levels are consistent with every day levels of radiation from various other sources, such as natural radon. Additionally, the atmosphere and water retains radioactive particles from past nuclear detonations, nuclear weapons testing, and other nuclear power plant accidents.

In 2008, Stone installed a mercury sampler in the Park for a two-year study, which was a part of a larger mercury monitoring network encompassing South Dakota and surrounding western states. Because of potential health risks, nearly all states in the United States have some form of fish advisory for their water bodies, most of which are based on high levels of mercury. Currently there are no mercury advisories in the Black Hills of South Dakota, but there are large information gaps within the region. This study was designed to fill some of these gaps. Results indicated mercury levels ranging from 0.1 to 3.3 in the Park from October 2008 through November 2010 (*Stone 2011)* (Figure 4).

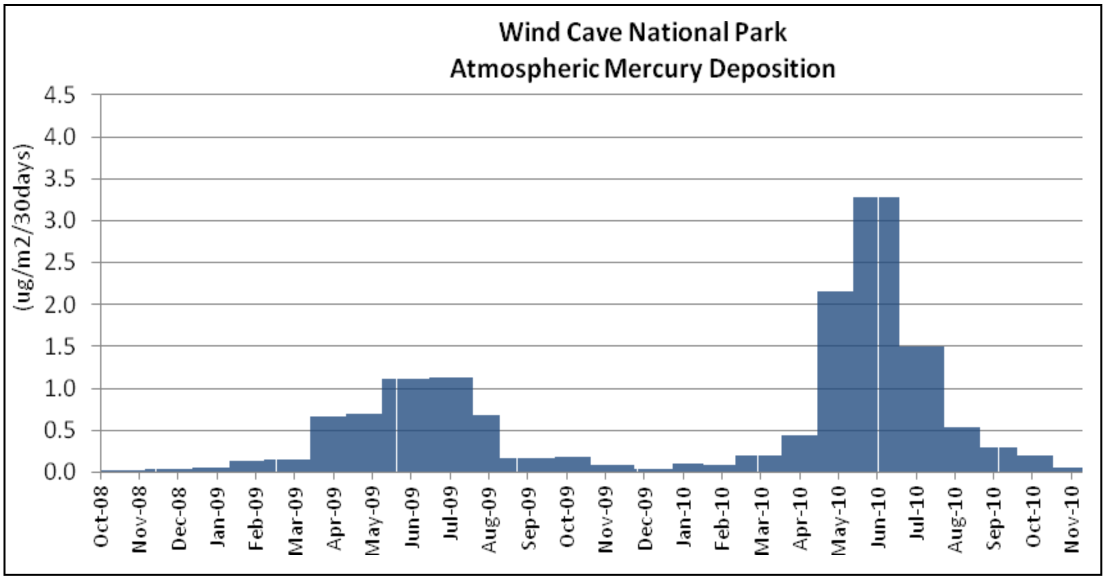

Figure 4. Atmosheric Mercury at Wind Cave *(Stone 2011*)

Surface Water

The park lies within the Cheyenne River Basin, which is a part of the greater Missouri River watershed. The amount of surface water present in the park is greatly dependent upon precipitation. During times of abundant rainfall, there is an excess of surface water in the Park. In contrast, when precipitation is sparse the streams, springs, and pools are reduced in size and many completely cease to exist. Periods of low water greatly affect the Park's wildlife, especially large ungulates.

Streams

There are three perennial streams within the boundaries of the park: Beaver Creek, Cold Spring Creek, and Highland Creek. All three stream's watersheds extend well outside of the park (Figure 5). Other drainages and canyons occasionally flow intermittently during storm events.

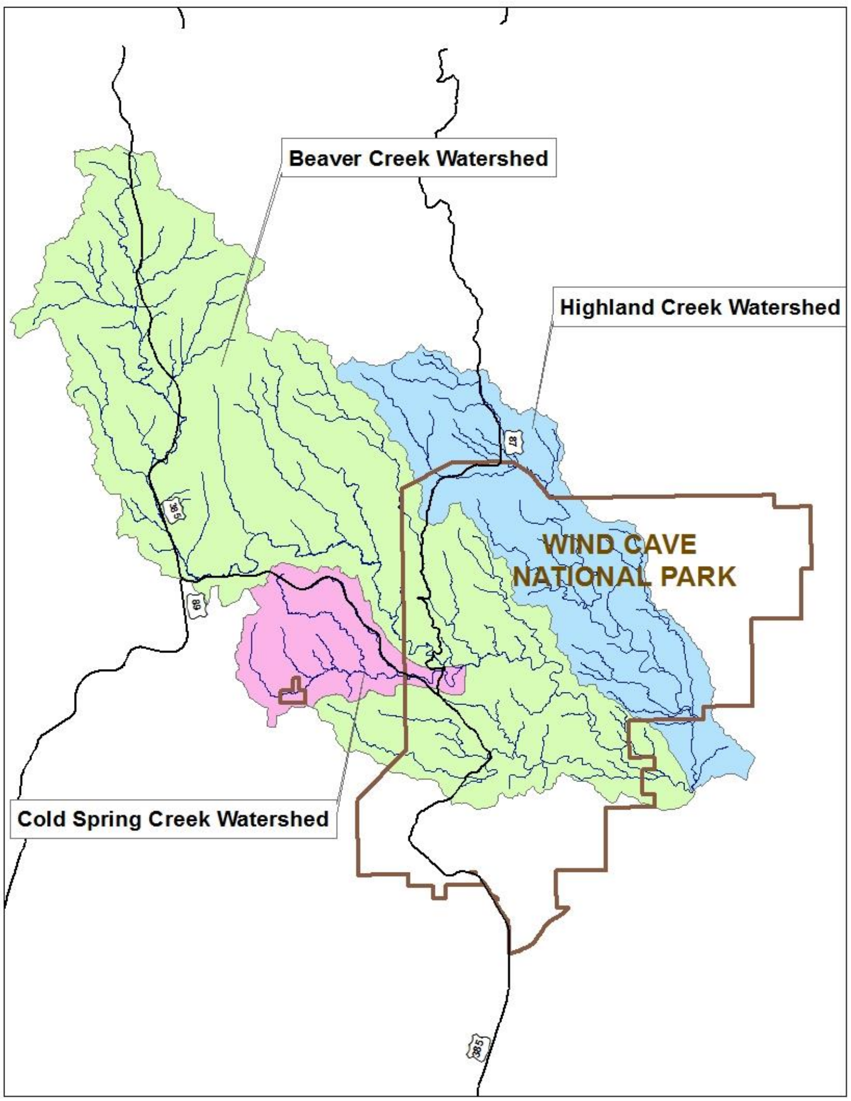

Figure 5. Watersheds of the park's perennial streams (*NPS*)

Beaver Creek

Beaver Creek is the primary drainage in the park, and all other perennial streams (Highland and Cold Spring) discharge into Beaver Creek whenever flows are sufficiently high. Beaver Creek drains an area of approximately 46 square miles. It begins south of the town of Custer and flows south to Pringle then east into the park. It continues flowing east through the park then continues southeast to join the Cheyenne River east of Buffalo Gap. However, the flow rarely continues out of the park as it typically loses its entire flow to infiltration as it crosses outcrops of Madison Limestone. The outcrop areas that capture stream flow are known as loss zones. These infiltration losses play an important role in recharging the Madison Aquifer.

In April of 1998, discharge measurements were taken by the Park above and below the loss zone to measure the infiltration losses. It was determined that the Beaver Creek above the loss zone was flowing at 5.67 cubic feet per second (cfs) and below the loss zone at 1.99 cfs. Thus, the discharge into the loss zone was 3.68 cfs or 27.5 gallons per second. This means that in a 24-hour period 2.4 million gallons of water entered the aquifer from Beaver Creek. During 1999, 2000, and again in 2015, the stream contained enough water that the loss zones within the Madison reached their maximum infiltration rates (loss threshold), which permitted excess water to flow beyond the park and into the Cheyenne River.

In a 1986 dye tracer study, dye that was injected into Beaver Creek to determine the water's flow path, was detected in the park's water supply well #1 after one month. The dye persisted for several months. The study exemplified the surface to subsurface hydrologic connection (*Alexander and Davis 1989b*).

Beaver Creek's earliest record of a flow measurement was taken in 1967, and the stream was discharging at 1.1 cfs (*Adolphson and LeRoux 1974*). In the fall of 1990, the U.S. Geological Survey (USGS) installed a stream level recording gage on Beaver Creek just below the confluence with Cold Spring Creek. This station is still in operation and has provided over 20 years of continuous flow data (Figure 6).

Cold Spring Creek

Cold Spring Creek enters the park at the west boundary along highway 385. It is the smallest perennial stream in the park in regards to stream flow and watershed area. The flow is largely derived from the Water Supply Springs via a series of cast iron pipes. When the Water Supply Springs served as the main water supply for the park, its overflow was directed into the Cold Spring Creek drainage. In addition to the flow from the pipes, the drainage receives some flow from runoff. However, the watershed is not large and during dry times the only discharge comes from the pipes. The Park plans to install a weir near the discharge to monitor the amount of water coming from the system.

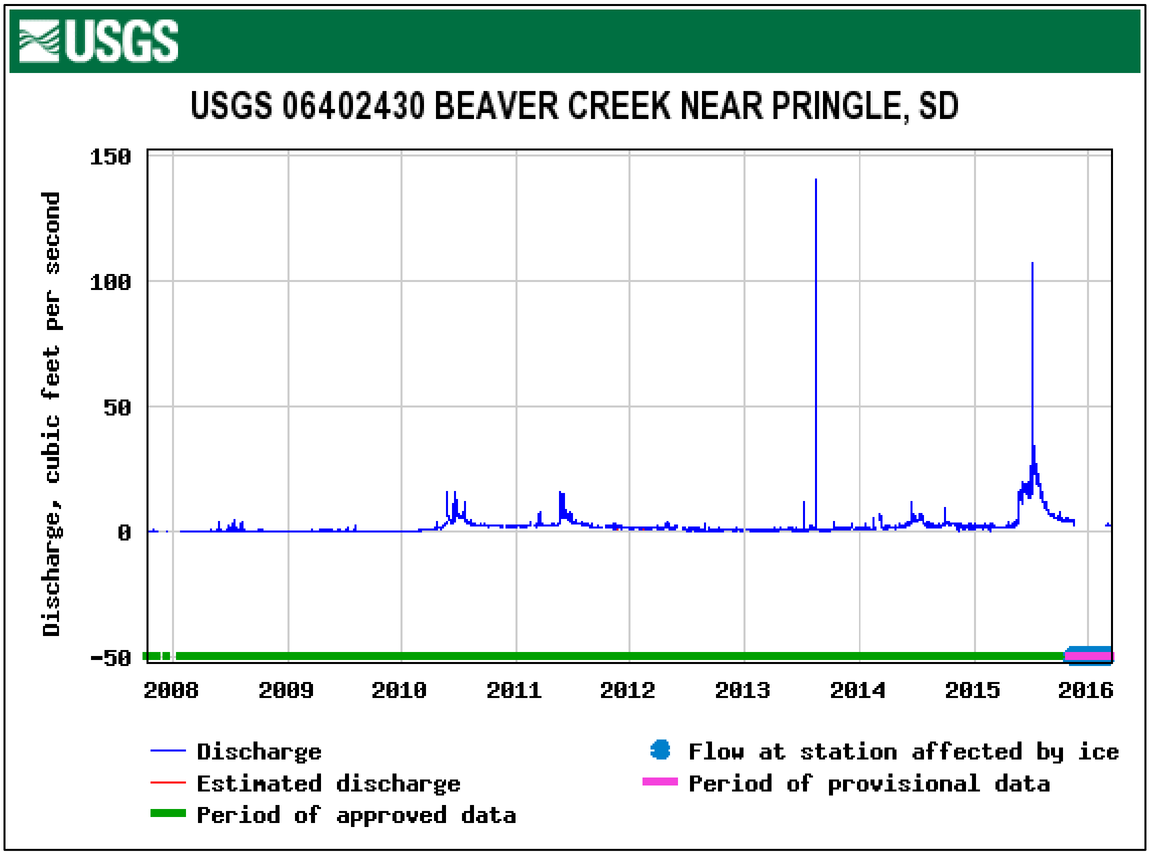

Figure 6. Stream flow of Beaver Creek (*USGS 2008 to 2016*)

Norbeck Dam is the largest and probably the most notorious dam built within the park. It was built in 1929 on Cold Spring Creek to provide water for wildlife. The dam was not effective as a water supply because its reservoir simply drained away into the underlying alluvium, the Deadwood Formation, and perhaps through the dam itself. By 1936, debate and concern about the project increased. The park requested funding to improve the dam but was denied in favor of removing the dam and restoring the area. The dam was decommissioned in 1989. Since the highway went across the dam, it was not feasible to remove it. So, a culvert was placed through the bottom to allow the creek to flow freely (*Bureau of Reclamation 1983*).

Highland Creek

Highland Creek's headwaters begin at a collection of small springs in Custer State Park, about ¼ mile from the park's northern boundary. The watershed receives some local runoff but it is largely spring fed. The amount of springflow depends on precipitation. Low precipitation translates to lower springflow and lower streamflow in Highland Creek. As the creek enters the park it flows across the Madison Limestone and begins to lose flow to infiltration, much like Beaver Creek. Depending upon flow conditions, the stream may end at the loss zone. However, if the flow is substantial, the creek continues downstream until it finally loses the remainder of its flow to loss zones within the Minnelusa Formation. In the spring of 2008, a new sinkhole was observed in the streambed shortly after the creek enters the park. The sink hole captured the creek's entire flow for several months. Eventually, the sink hole collapsed naturally and filled in. Currently, the stream again flows beyond the loss zone point. Dye was injected into the newly formed sink hole but the dye was not detected in Park Well #2 or in any of the lakes within Wind Cave (*Ohms 2012b*).

Photo 1. Injecting dye into Highland Creek (*NPS photo*)

Springs

There are ninety-seven springs documented within the Park (Figure 7). The springflow largely depends on precipitation, and most of the springs do not discharge during dry periods. Of the ninety-seven springs, nine currently have developments (spring boxes and water tanks) to provide water for animals. Early in the park's history cattle grazing was permitted. To provide water for grazing, the park altered several of the springs' flow channels and built numerous stock dams. Cattle grazing is no longer permitted within the park, but the improvements have been left in place to provide water for wildlife. Several other spring outflows have since been altered solely for wildlife benefit.

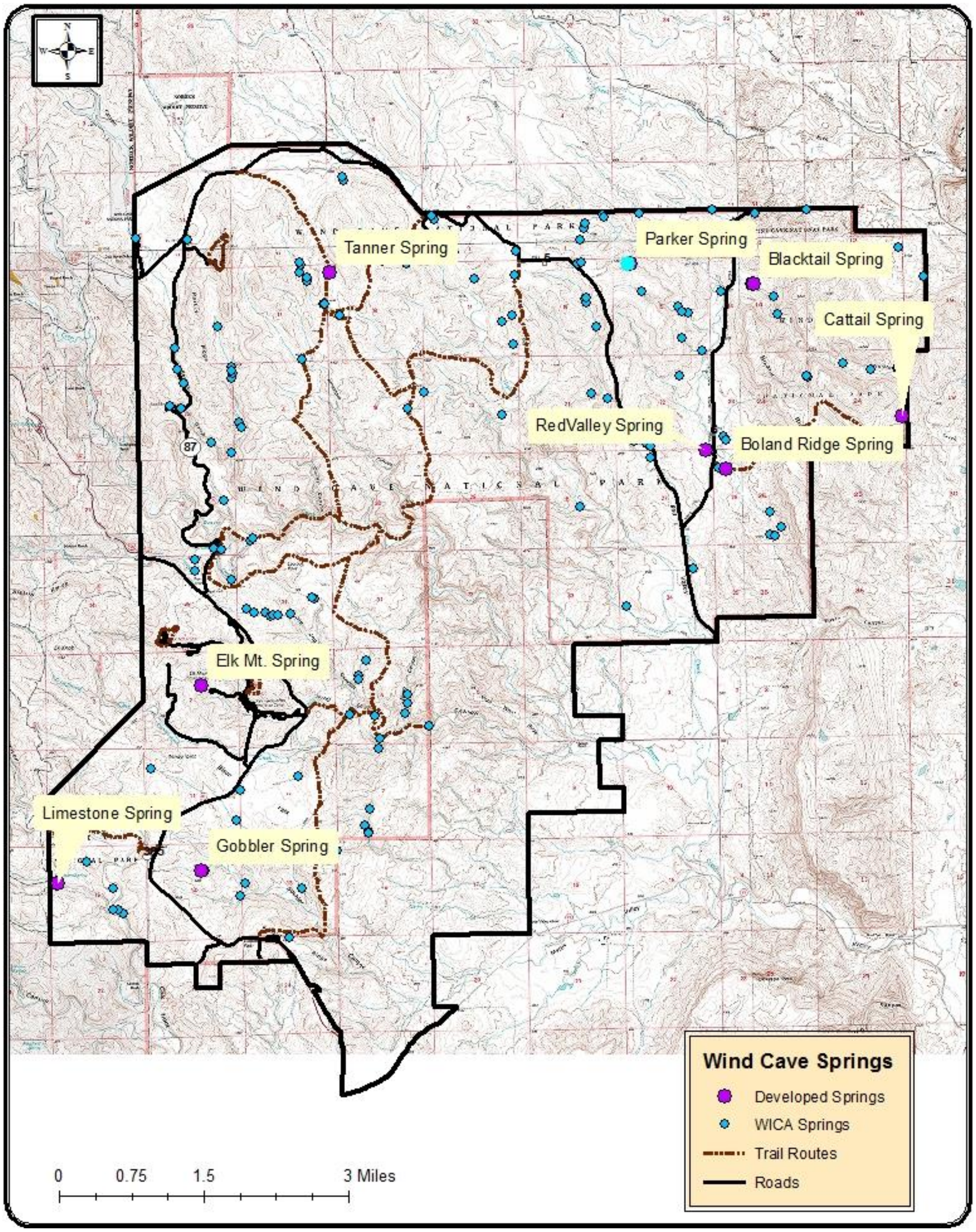

Figure 7. Springs within Wind Cave National Park *(NPS 2016*)

The springflow within the park rarely produces more than 3 gallons per minute (gpm). Typically, the flow is derived from inter-flow within the soil zone or alluvium with little to no bedrock flow. Alluvial springs are difficult to study because they tend to migrate based on the amount of water within the system.

During 1987-88, the Park located and documented numerous springs as part of a comprehensive water study. Flow rates and water temperature were documented at many of the sites (*Schroeder 1989*). During the summers of 2000 and 2004, 186 water sites within the park were documented with the primary purpose to gather information regarding water availability for wildlife (*Clark 2000, Liddick 2004*).

Beaver Creek Spring is a large outflow of groundwater located in the Beaver Creek drainage south of the park on private property. The landowners graciously have allowed the park to conduct water sampling and discharge measurements. Many ranchers depend on water from this spring for irrigation and livestock. The nearby Trout Haven Ranch depends on the water to raise trout.

Routine discharge measurements of the spring are made using the standard wading method as per protocols established by the United States Geological Survey (*Rantz et al. 1982*). Flow measurements have been taken on a semi-monthly basis since 2009 and have ranged between 8.95 and 16.2 cfs (Figure 8). There are periods of time that surface water flow upstream of the spring contributes to spring flow; measurements taken during these times are not included in Figure 6 since it would not represent spring discharge. Although the spring is not within the park, obtaining discharge measurements is part of a larger effort to obtain a better understanding of the Madison Aquifer, and the potential effects from increasing groundwater withdrawals (*Ohms 2010b*).

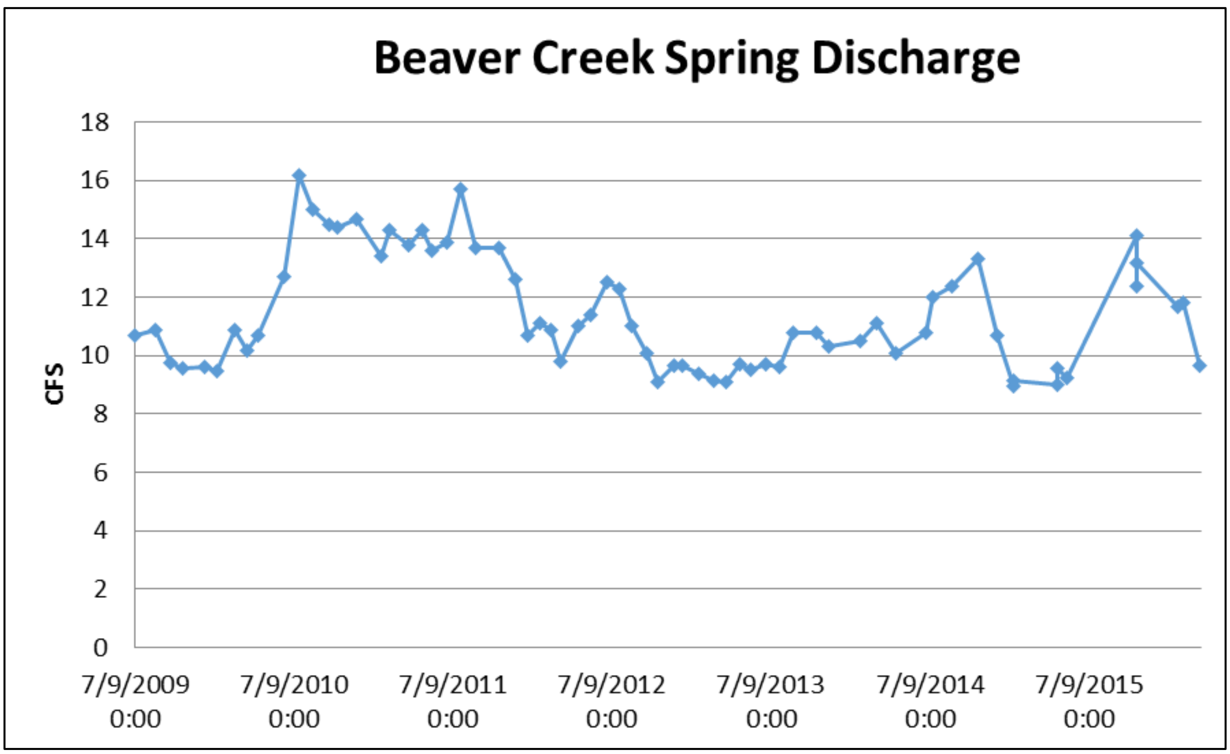

Figure 8. Discharge of Beaver Creek Spring (NPS 2009-2016)

Photo 2. Taking discharge measurement at Beaver Creek Spring (*NPS photo*)

Surface Water Quality

In 1998 the NPS Water Resource Division cumulated and summarized a large volume of water quality data dating from 1971 to 1998 from the cave and surface waters. While primarily a reference document it did state that several sites have had elevated levels above screening criteria for a variety of constituents, indicting the water sites are being impacted from human activities (*NPS 1998*).

In 2002 and 2003 the USGS conducted water quality characterization of the three park streams. In Beaver Creek it was found that the water quality was somewhat degraded compared to the other two park streams, indicating that activities outside the park could be influencing the quality of the stream (*Heakin 2004*). Concentrations of E. coli, fecal coliform, and total coliform bacteria were highest in Beaver Creek. The sediments in the stream contained arsenic concentrations of 9.4 mg/g, exceeding the EPA's threshold for stream sediments. Phenol, para-cresol, and para-nonylphenol, which are manufactured chemicals found in a number of consumer products, also were found in the stream. Cholesterol and caffeine were also found, which indicates that septic system(s) likely are affecting the stream's water quality.

During a 2002/03 USGS study, four wastewater compounds were detected in the Cold Spring Creek, indicating that activities outside the park were influencing the quality of the stream. Similar to the results from Beaver Creek, concentrations of bromoform, phenol, caffeine, and cholesterol were found. Additionally, arsenic concentrations from bottom sediments were recorded at 9.5 mg/g, which exceeds the U.S. EPA threshold effects guidelines (*Heakin 2004).*

The 2002/03 USGS study found that the highest concentration for dissolved nitrite plus nitrate was from Highland Creek. However, no wastewater compounds were found at levels above the minimum reporting level (*Heakin 2004*).

In 2012, from June to September, the Northern Great Plains Inventory and Monitoring Program conducted a small-scale water quality sampling study in the three perennial streams in the Park. The primary goal of this pilot project was to determine the feasibility of using standard microbiological procedures for water quality analysis of indicator bacteria levels within the park's boundaries.   Cold Spring Creek had the lowest amount of *E. coli* while Beaver Creek had the highest amount (*Murray, et. al. 2015*).

Groundwater

The Park lies in the heart of the recharge zone for the regionally significant Madison and Minnelusa Aquifers. The aquifers serve as a drinking water source for the park as well as the local area, including the community of Hot Springs. Much of the recharge to the aquifers comes from stream flow losses as streams cross outcrop areas of the karstic limestone.

The Madison Aquifer is part of the Mississippian age Madison Limestone Formation and ranges in thickness from 295 feet to about 850 feet (*Palmer and Palmer, 2009*). The Pennsylvanian and Permian age Minnelusa Formation was deposited on top of the Madison and is comprised of limestone, sandstone, dolomite and shale.

Water movement through the aquifer's karst features is dynamic, allowing for rapid response of groundwater levels following substantial recharge events. Large secondary porosity resulting from solution openings causes the cave and aquifer to be extremely vulnerable to contamination from infiltrating surface water. Beaver and Highland Creeks generally lose all of their surface flow to the underlying bedrock aquifers within the park boundaries. Dye tests conducted in 1987 showed that dye injected into Beaver Creek within park boundaries was detected in Park Well #1 within 2 months (*Alexander and Davis 1989b*). Thus, a hydrologic connection has been established between Beaver Creek and the subsurface.

The Deadwood Aquifer underlies the Madison Aquifer separated by the Englewood Formation. Generally, there is scarce water mixing between the aquifers because of the low permeability and shale nature of the Englewood Formation. However, mixing occurs in some areas. The Deadwood Formation outcrops along Cold Spring and Beaver Creeks within the park boundaries. At these outcrops, the Deadwood Aquifer receives recharge from precipitation.

Wells

There are sixteen reported wells located within the park (Figure 9). Most of the wells were constructed prior to the park's establishment. Six of the wells are within the Madison Aquifer; however one well never hit water (O'Neil Well) as they stopped drilling after hitting a six-foot high void. Seven of the wells are within the Minnelusa Aquifer, and three of the wells are undetermined at this time.

Elk Mountain Spring is located on Elk Mountain, just west of the Park's Visitor Center. In the early 1900's this spring served as the water source for the park's headquarters area, but by 1926 the spring was not producing enough to meet the demand of the park. To remedy the water shortage, the land on which Water Supply Spring is located was purchased from McAdams in 1931 to supply the park with water. At this new site, water from a series of springs was collected in a storage gallery and piped into the park. When the Water Supply Spring was first developed it produced up to 24,000 gallons a day. The years following saw low precipitation and the springs flow was greatly reduced. In 1940, the supply did not meet the demand and water was hauled in from Hot Springs. Wetter years soon followed and the spring was once again producing abundant water. The next dry period was during the early 1950's. By 1954, the spring was producing only 5,000 gallons a day. In 1955, 240,000 gallons of water were trucked to the park from Hot Springs. In 1955, the park decided to drill a well due to the unreliability of the springs. (*Wind Cave Superintendent Annual Reports 1910-2002*)

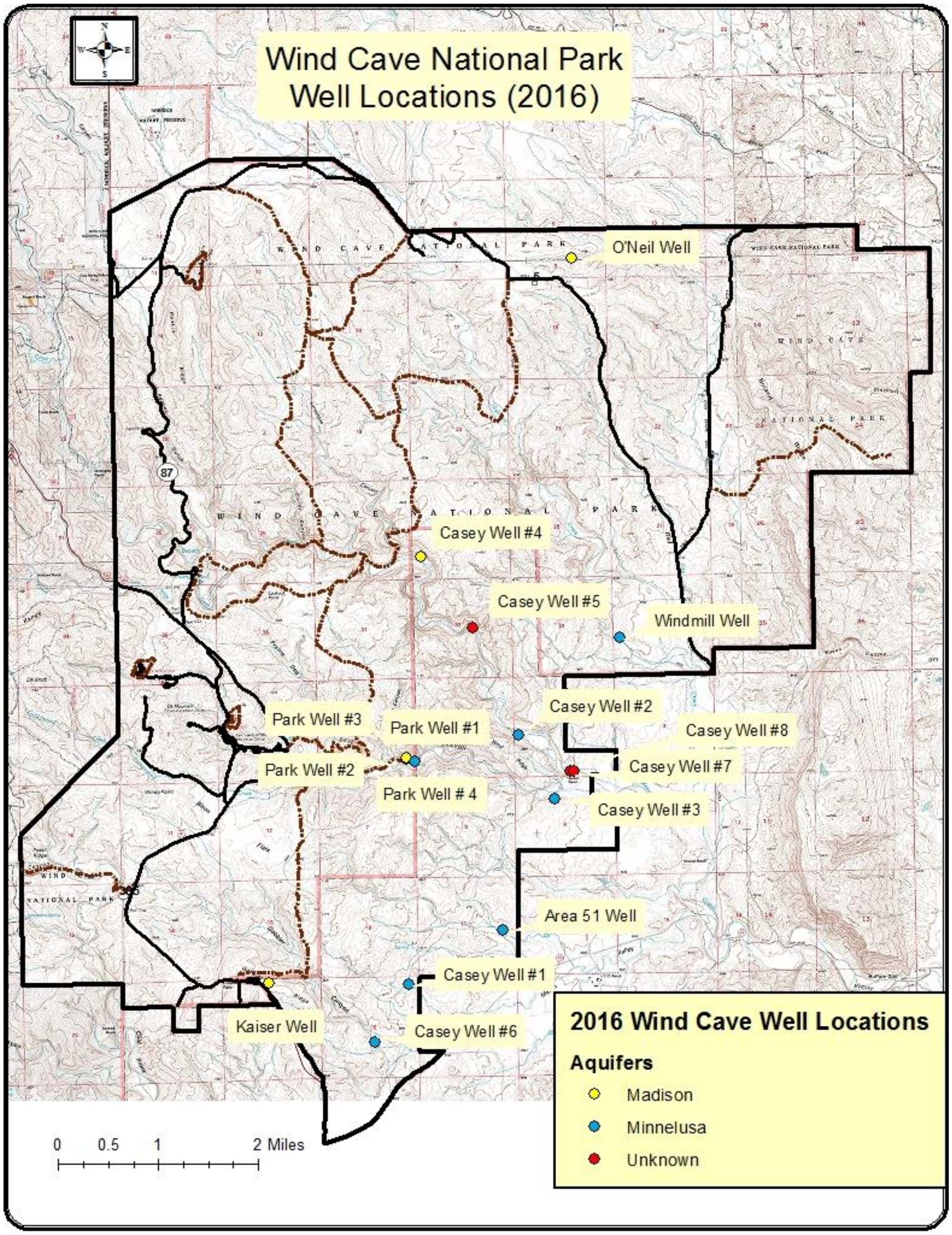

Figure 9. Wells within Wind Cave National Park (*NPS 2016*)

Park Well #1 was drilled in 1956 by the Sioux Drilling Company to a depth of 790 feet. This well was to supplement the Water Supply Springs source that in the preceding years was not found to be adequate. The well reaches into the Madison Limestone where it intersects the Madison Aquifer, and continues down through the Englewood and Deadwood Formations to the igneous rock. There were problems with large quantities of red sediment in the water during initial tests, hence the reasoning for drilling the well deeper than probably necessary. Because of the well's bent bore hole, the well was cased only to 590 feet and the remaining was uncased. As of 2016 the well continues to serve as the park's main water supply.

In October of 1971 an aquifer test was conducted on Park Well #1. The well was pumped at a rate of 40 gpm for 24 hours, lowering the water level 120 feet. After pumping ceased, the water level recovered within 263 minutes (*Adolphson and LeRoux 1974*).

To determine the age and the residence time of the water from the well, the levels of tritium and carbon isotopes were measured in 1989. It was determined that the water in the well was dominated by very recent water- water that infiltrated into the ground from precipitation in a few months to a year (*Alexander and Davis 1989b*). This supported the results from Alexander's dye trace that indicated the water from Beaver Creek reaches the well within two months.

Park Well #2 was drilled in 2002 to a depth of 685 feet, placing it in the Madison Aquifer. The well was drilled to supplement Park Well #1. However, the well's arsenic and fluoride levels exceeded the current MCL (maximum contamination level). Therefore, the well is unusable for public drinking water. In 2010, the pump was removed from the well and it serves as a monitoring well only (Figure 10).

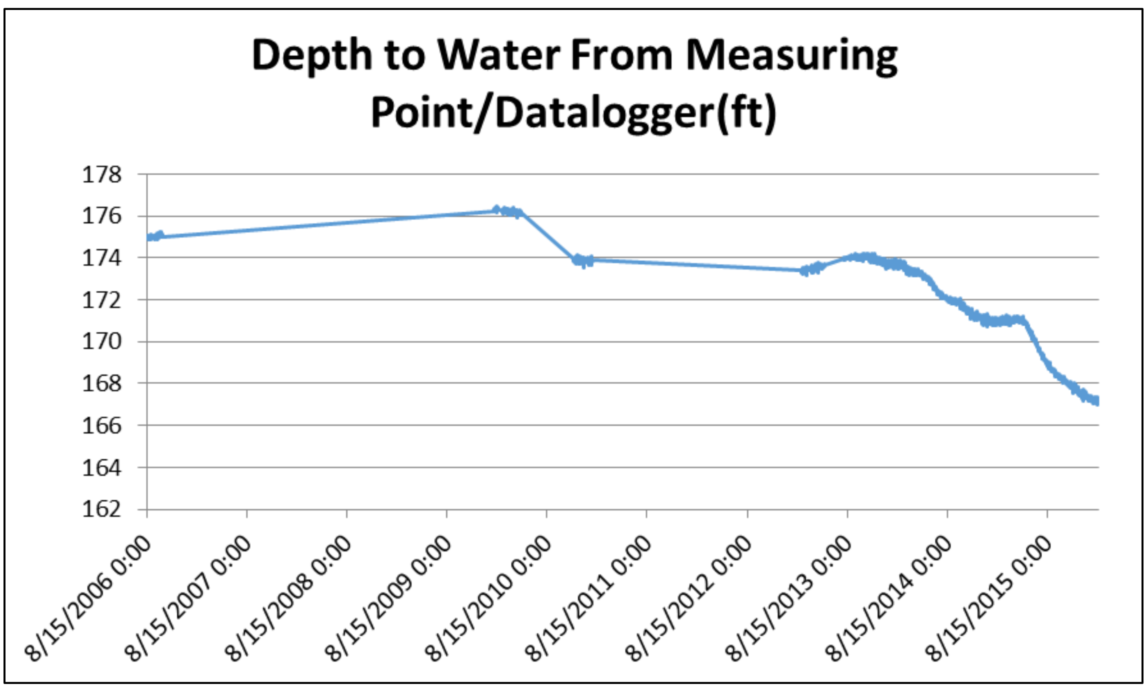

Figure 10. Park Well #2 water levels (*NPS 2006-2015*)

In the summer of 2007 a pump test was performed on Park Well #1 to determine the effects of drawdown on Park Well #2. The wells are located less than 100 yards apart. The well was pumped for 72 hours. Surprisingly, no drawdown was observed in Park Well #2. (*Hughes and Cutillo 2008*).

To continue to find a backup water source, in 2010 the park drilled Park Well #3 within 50 feet of Park Well #2 to find potable water. However, similar to Park Well #2, well #3's water tested high in arsenic. Thus, the well was plugged and abandoned. Another attempt, Park Well #4, within 50 feet of Park Well #1, was successful. This well produced good quality water within the Minnelusa Aquifer at a depth of 400 feet.

We have no records as to when Windmill Well was constructed; however it was prior to the land being part of the park and used for watering livestock. The depth of the well is 72 feet and within the Minnelusa Aquifer. A data logger was in place from 2010 to 2015 and water depth varied greatly from a low of -55 feet to a high of -18 feet (Figure 11). The water levels responded quickly and rather dramatically to large precipitation events.

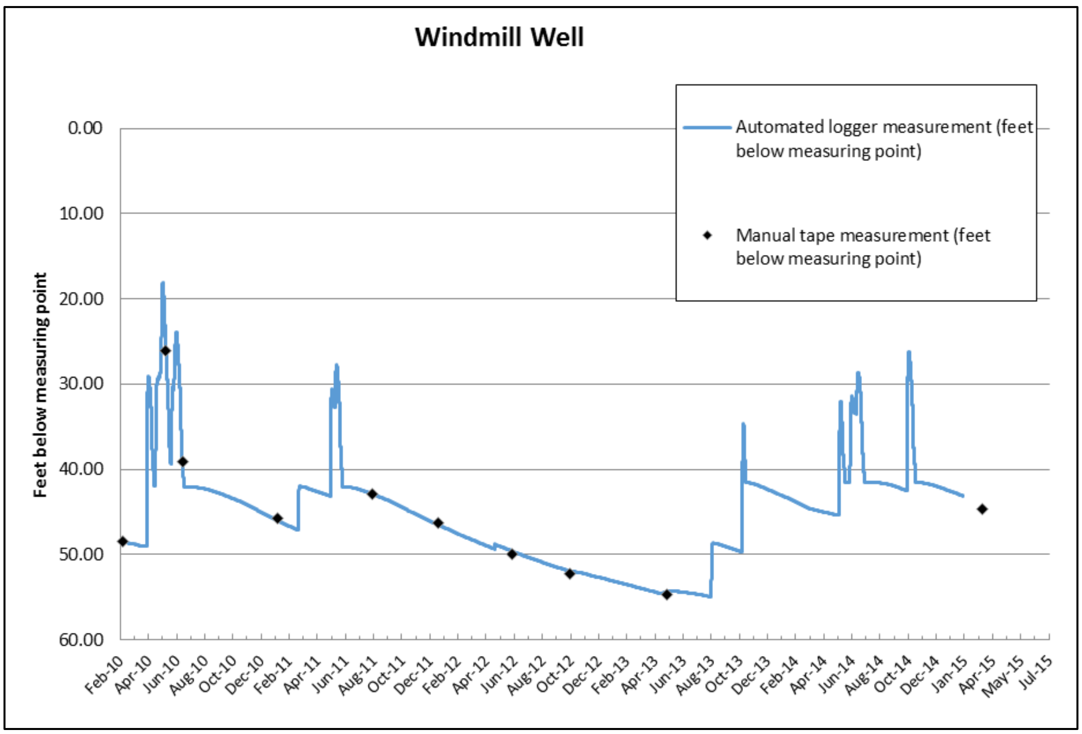

Figure 11. Water levels in Windmill Well (*NPS 2010-2015*)

Recent land acquisitions by the Park of the Casey Ranch at its southern end added nine wells, including one within the Madison Aquifer (Casey Well #4). The majority of these wells served as water sources for animals. The park is considering continuing this practice for wildlife. In addition, the recent acquisition of the Job property at the southern end of the park added another Madison Aquifer well (Kaiser Well).

Wind Cave

Wind Cave formed in the Madison Limestone and there is currently over 145 miles of documented passage with more discovered every year. The cave is deep enough to intersect the water table of the Madison Aquifer, where several large groundwater lakes are present (Figure 12). The Lakes have provided a unique opportunity for underground research unprecedented globally. In addition to the groundwater lakes there are currently 1,500 drip sites, 200 perched pools, and 3 places of constant running water documented in the cave.

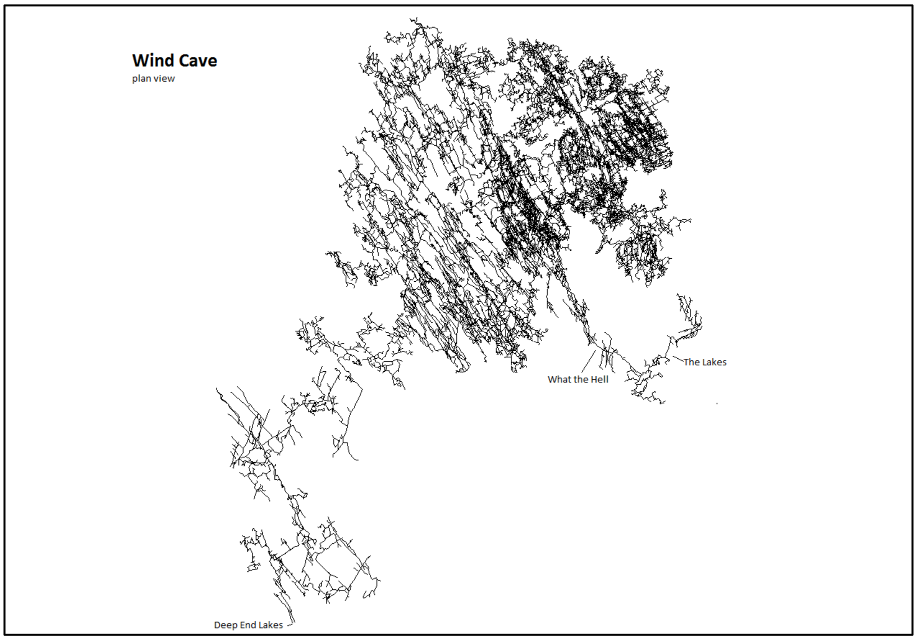

Figure 12. Plan view of Wind Cave showing the location of the Lakes. (*NPS*)

Starting in September of 1986, the park established a staff gage at the Lakes to record the water levels (Figure 13). Measurements have been taken sporadically since. The Lakes are only accessible to experienced cavers as the route takes several hours of crawling, climbing, and squeezing to get to the site. To increase measurement frequency the Park installed a data logger to record water levels.

Miller analyzed the oxygen isotopes within the cave lake water and concluded that the water was meteoric, and that the water was supersaturated with respect to calcite and dolomite (*Miller and Dickey 1987*). After analyzing the water chemistry of the cave lakes and park surface streams, Miller concluded that the surface streams were not the source of water for the cave lakes (*Miller 1989*).

In 2008 a qualitative dye trace was conducted to determine the interconnectivity of What the Hell Lake and Calcite Lake. Four liters of green fluorescein dye were injected into What the Hell Lake. Dye receptors were placed in Calcite Lake to detect if the dye passed through the sites. A month after the dye injection, What the Hell Lake still retained much of the dye. It was discovered that the dye also was present at Calcite Lake. Over two years after the dye injection, Calcite Lake still contained dye, although it was no longer visible. Samples taken from the two park wells did not indicate any dye (*Ohms, 2010a*).

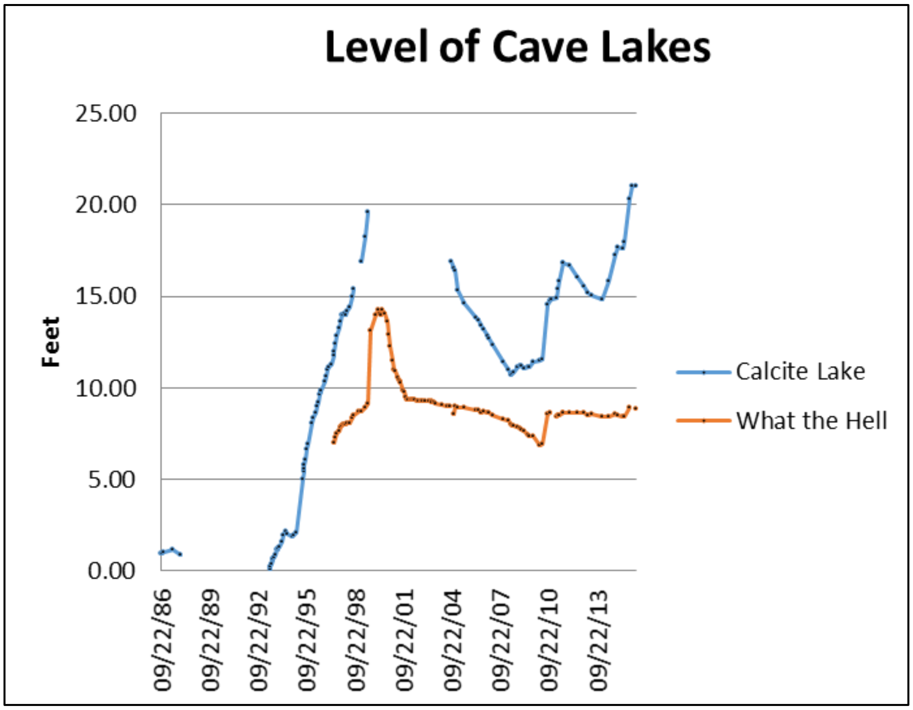

Figure 13. Lake levels from staff gages- (NPS *1986-2015*)

Photo 3. Drip water collector in Wind Cave (*NPS photo*)

Zara Environmental conducted a survey for groundwater macro-invertebrate fauna in and around the park. Lakes within Wind Cave were the focus of the study, but wells and springs in the surrounding area also were sampled for comparison. Visual searches, plankton nets, drift nets and baited traps at

19 different sites were used in an effort to capture fauna. No groundwater macro-invertebrate fauna were detected at any of the sites (*Zara Environmental*, *2009*).

Barton (*2011*) sampled water from Calcite Lake to examine the micro fauna as a representative community of microorganisms living within this unique aquifer. In addition to sampling water within Wind Cave, Barton also examined microbial communities in other sites from the aquifer including Beaver Creek Spring, Park Well #2, and Streeter Well. These sites were both within and outside the boundaries of the Park. Barton's study represented the most comprehensive examination of a microbial community within a cave environment to date. The study found that the micro fauna of Calcite Lake represents a unique microbial community, with a highly diverse microbial community despite total cell numbers well below those previously observed in freshwater environments. The water in Calcite Lake has extremely low biomass, far below any encountered for any karst environment, aquifer or other studied body of water (*Barton 2011*).

Photo 4. Microbiological sampling at Calcite Lake (*NPS photo*)

Photo 5. Searching for macro-invertebrates in Wind Cave (*NPS photo*)

Back *(2011)* used major ion chemistry, stable isotopes of water, and geochemical modeling to investigate the origin and chemical evolution of water found in the underground lakes. Back discovered that stable isotope and water chemistry data combined with water level data show that local recharge to underground lakes is the primary source of water. Flow is generally east and southeast from the park, following the dip of sedimentary units flanking the Black Hills uplift. Regional flow from the west mixes with local recharge south of the park, and mixing is evident in the stable isotope composition of spring discharge. A mixture of local recharge and regional flow from the west, combined with the process of dedolomitization, account for the water chemistry of large springs that discharge from the Madison aquifer in the Southern Black Hills.

A study of groundwater flow, quality, and mixing in relation to the Park was conducted by the USGS in cooperation with the NPS because of water quality concerns and to determine possible sources of groundwater contamination in the area. A large area surrounding the Park was included in this study because to understand groundwater in the Park, a general understanding of groundwater in the surrounding southern Black Hills was necessary. Three aquifers were of particular importance for the study: the Minnelusa, Madison, and Precambrian. Multivariate methods applied to hydro chemical data, consisting of principal component analysis (PCA), cluster analysis, and an end-member mixing model, were applied to characterize groundwater flow and mixing. This method provided a way to assess characteristics important for groundwater quality, including the differentiation of hydrogeological domains within the study area, sources of groundwater, and groundwater mixing. Groundwater and surface-water samples collected for this study were analyzed for common ions, arsenic, stable isotopes of oxygen and hydrogen, specific conductance, and pH. A total of 100 samples were collected from 60 sites from 2007 to 2011 and included stream sinks, cave drips, cave lakes, springs, and wells.

The study estimated that Wind Cave sites received 38 percent of groundwater inflow from local surface recharge, 34 percent from the up-gradient Precambrian aquifer, 26 percent from surface recharge to the west, and 2 percent from regional flow. Artesian springs primarily received water from end members assumed to represent regional groundwater flow. Groundwater samples were collected and analyzed for chlorofluorocarbons, dissolved gasses, and tritium at selected sites and used to estimate groundwater age. Apparent ages, or model ages, for the Madison aquifer in the study area indicated that groundwater closest to surface recharge areas is youngest, with increasing age in a down-gradient direction toward deeper parts of the aquifer. Arsenic concentrations in samples collected for this study ranged from 0.28 to 37.1 micrograms per liter (µg/L). The highest arsenic concentrations in and near the study area are approximately coincident with the outcrop of the Minnelusa Formation and likely originated from arsenic in shale layers in this formation (*Long et al. 2012*).

In 2009, a series of pools (Deep End Lake) were discovered at the southwestern most point of the cave. It was believed to be the water table but due to the remoteness of the site, no sampling or research has yet been conducted.

Photo 6. Deep End Lake (*NPS* photo)

Water Rights

The Park currently has four South Dakota State Appropriative Water Rights (*Hughes 2016*). The first dates back to 1937 for 90 gpm of water from the Water Supply Spring System on Cold Spring Creek. In 1939 the Park obtained a permit to store 222 acre feet per year of water in Norbeck Dam. In 1955 a permit was issued to the Park for 67 gpm of water from Park Well #1. In 1998 a second well (Park Well #2) was completed and simply added to the existing permit as an additional source. In 2011 Park Well #4 was completed and permitted for 50 gpm.

Impacts on Water Resources

Threats to the quality and quantity of the water resources of the Park exist within and outside of the park's boundaries.

Groundwater Withdrawals

Groundwater in the southern Black Hills is a vital resource to the Park and the nearby ranches and local communities. In 2006, a project to create a rural water system using water from the Madison Aquifer was initiated. A total of five 10-inch diameter wells were planned to be drilled to supply the system, with two of the wells located within one mile of the southern park boundary. Removing large quantities of groundwater so close to the recharge area has the potential to greatly affect the park's water supply wells, and for the first time in recent geological history, the groundwater lakes within Wind Cave could vanish. As of 2016, the project remains on schedule. Pipelines were constructed, pump stations installed, a water tower was erected, and customers are receiving water. As the population of the Black Hills continues to grow, so does the need for water. With low volumes of useable surface water, groundwater becomes an increasingly important commodity. The Park with assistance from the NPS Water Resource Division's Water Rights Branch, is continuously monitoring future well applications, and requesting water use records from the larger users in the area.

Vegetation

A lack of wildfire can influence the amount of regional infiltration and transpiration by allowing Ponderosa Pine to increase in density and to excessively encroach upon the prairie areas. In the past, fires were viewed negatively and suppressed. However, recently the necessity of fire to manage lands has become better understood. Over the past twenty years, the park has maintained an active prescribed fire program, helping to restore the role of wildfire in the ecosystem. A goal of the Park's prescribed fire program is to manage local water resources by controlling vegetation.

In 1935 the Civilian Conservation Corps (CCC) planted 5,000 trees and shrubs in the Park's Visitor Center area. Photographs taken during that time were compared to recent photos (below) to determine the effects of the vegetation on local watersheds. Recent photographs showed denser forests with increases in Ponderosa Pine growth (*Pace-Graczyk and Ohms 2006*). As seen in the pictures below, the CCC's efforts greatly increased the amount of vegetation in the area, which in turn decreased water volumes entering the cave network. This section of the canyon consists of a small outcropping of the Madison Limestone, which allow water to readily infiltrate into the subsurface aquifers. In 2011, the park began a project to remove non-native trees and excess native trees within the Wind Cave Canyon area around the Visitor Center.

Photo 7. Bringing fire back into the ecosystem thru prescribed burning (*NPS photo*)

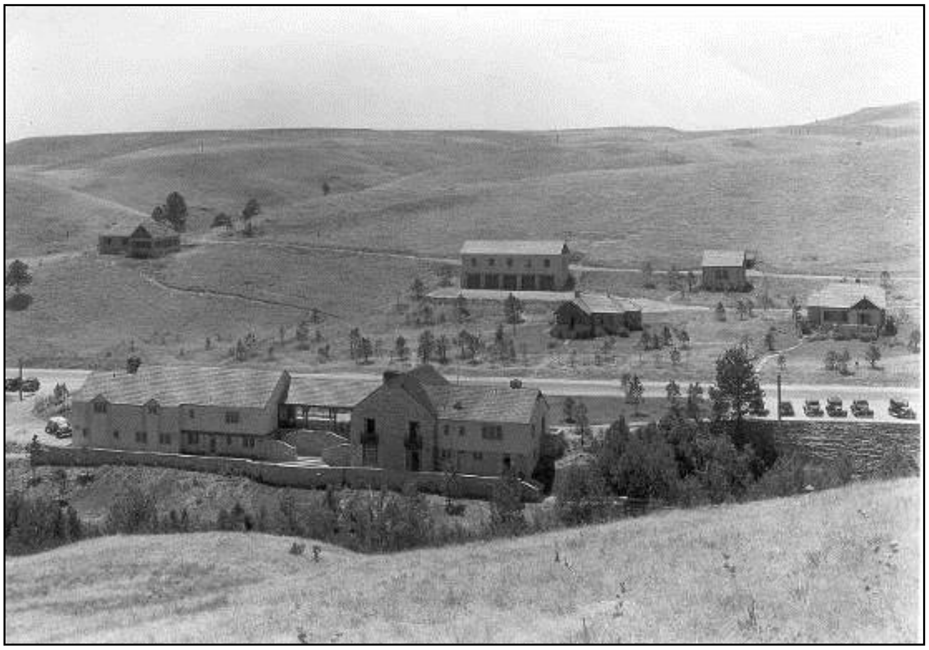

Photo 8. Visitor Center area in 1935 (*NPS photo*)

Photo 9. Visitor Center area in 2005 (*NPS photo*)

Photo 10. Wind Cave Canyon before thinning (*NPS photo*)

Photo 11. Wind Cave Canyon after thinning (*NPS photo*)

Pesticide Use

Pesticide application to reduce non-native plant species occurs both inside and outside of the Park. Many pesticides can remain in the environment for an extended period of time and can migrate into surface and groundwater. Pesticide use is one of the leading causes of surface and ground water pollution across this country. Recent studies from the USGS concluded that over 95 percent of the rivers and streams in the US, and 50 percent of the wells in the country, contain pesticides (*Gilliom et al. 2006*).

To help protect water resources the Park established three zones of management for pesticide use. The zones are the Spray Zone, where there appears to be no known resource concerns (i.e. flowing surface water, karst features, native plants of concern, etc...), the Limited Spray Zone, where limited areas of concern exist, and the Restricted Spray Zone, where areas of concern exist and spraying will not occur or have extremely limited use. To accompany the management zones, the park designed a Pesticide Water Monitoring Plan in which water sampling protocols were established. The sampling time interval is based upon five factors: the zone in which application is conducted, the pesticide used, the method of application, the geology/hydrology of the site, and pre and post-application precipitation (*Ohms 2012a)*.

Park Infrastructure

Most of the park's infrastructure was built during a time when protecting the cave network and water resources were not the park management's primary concerns. This oversight likely was from a lack of understanding of the region's hydrogeology and surface-subsurface interactions. However, today's park management strives to better understand the network's connectivity and preserve the Park's cave and water resources.

Sewage System

Beginning in the early 1930's, the Park's infrastructure development proceeded at an accelerated pace largely due to a CCC Camp established at the park. Several employee houses, a larger visitor center, and an elevator building were constructed during this time. In addition, for the first time, all of the buildings were tied into an integrated sewage system, complete with several thousand feet of sewer lines. The sewer lines, like the buildings and other surface developments, were placed at convenient locations, such as beneath or adjacent to a dry stream bed and over the cave network. For the next 50 years, sewage system remained untouched. Beginning in the early 1980's, park staff studied the aging sewer lines. A slip-lining project was initiated, which installed long sections of plastic pipe into the deteriorating sewer lines. In 1993, following a small flash flood in the dry streambed near the sewer lines, the lines were clogged with sticks and other surface debris. (*Nepstad 1997b*)

In the summer of 1995, the Park purchased a sewer camera and the lines were inspected. The inspection found that while slip-lining was in place along the majority (but not all) of the main sewer line, only rarely were the lines which connected buildings to the main lines slip-lined. Only 40 feet of the 300 feet of sewage pipe between the Visitor Center and the main line could be inspected as much of it was invaded by vegetation roots, which breached the sewage lines. Most other unlined sections had problems because of the age of the pipes. Pipes were frequently blocked by large vegetation roots. Often, even slip-lined sections had problems. The welds joining sections of the slip-lining material were sometimes broken, creating gaps which frequently leaked. Dye traces documented that water entering the ground in the vicinity of the sewer lines can enter the cave in as little as six hours. (*Nepstad 1997b*) In 2000 the park's wastewater collection system piping was upgraded to dual-wall construction to eliminate infiltration as well as leakage.

Prior to 1989, the wastewater treatment system consisted of two unlined lagoons. Overflow was controlled by allowing effluent to infiltrate directly into the underlying and surrounding soils. In 1989, the ponds were lined to prevent wastewater from infiltrating into the soil and potentially polluting groundwater and cave resources. After the liners were installation, evaporation was the only means to eliminate wastewater from the ponds, but they reached capacity every three to four years. The lagoons were undersized and poorly located to accommodate the wastewater generated by park facilities and rainfall. Total inflow to the ponds consisted of approximately 2.5 million gallons of wastewater per year and 1.6 million gallons of rainfall, for a total of 4.1 million gallons. The annual evaporation rate at the ponds was about 40 inches per year, which removed 3.5 million gallons, leaving a net inflow of 0.6 million gallons per year. Since the amount of water entering the lagoons exceeded the amount evaporated, the lagoons filled to capacity. In 1993, 1.6 million gallons of wastewater were discharged from the ponds by pumping the water over an adjacent slope and spraying it on the prairie. Three years later in 1996, the two ponds were full again. Emergency funding was obtained to construct a third evaporation pond. Before construction of the third pond was finished, 600,000 gallons of wastewater had to be removed. The excess was trucked to Hot

Spring's wastewater treatment facility. Installation of the third pond increased total capacity to 6.1 million gallons. Despite the increase, by 1999 all three of the evaporation ponds filled. During 1999, 2.6 million gallons of wastewater were discharged onto the land. Another 1.6 million gallons were spray irrigated in the spring of 2000.The result was a total of 5.8 million gallons of wastewater distributed onto the land over seven years.   When the South Dakota Department of Environment and Natural Resources (SD DENR) issued the emergency discharge permit for the 2000 land application, the park was informed that future requests for discharge permits would be denied. The park was directed to find a permanent solution to the wastewater treatment problem. The SD DENR expressed concerns that due to the very high percolation rates in the area's soils, groundwater could be contaminated by wastewater discharged from the park's facility. (*National Park Service 2005a*)

In 2003 the NPS entered into consultation with Hot Springs and received approval from the City Council to pursue construction of the wastewater transmission line to connect to the City's municipal wastewater treatment system. In April 2004, the City of Hot Springs held a referendum on a measure to move forward with the wastewater agreement with the park. The measure was defeated by voters and further planning for the transmission line came to a halt. This resulted in the park choosing a different alternative analyzed in the environmental assessment to address their long-term wastewater management needs. (*National Park Service 2005a*)

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In 2007, three evaporation ponds were constructed in a different location to increase the effectiveness of the pond. The old ponds were removed and the site restored.

Parking Lot

Like most of the park infrastructure, the parking lot was constructed directly above the cave and adjacent to the drainage of Wind Cave Canyon. The runoff from the 2.5 acre parking lot drained directly into the canyon, and the water quickly infiltrated into the subsurface.

To determine if park infrastructure was impacting the cave, Alexander and Davis (*1989*) injected dye where the north end of the Visitor Center parking lot drains. Within a few days, dye was detected at three drip sites within Wind Cave, indicating that runoff from the parking lot enters the cave. Water from the three drip sites was then tested for hydrocarbons. Only one site tested positive for toluene, a common constituent of gasoline, and total hydrocarbons. At the south end of the parking lot, dye was injected into the drainage near the Elevator building where runoff from the parking lot enters the canyon. Seventeen drip sites within the cave were monitored for dye. Dye was detected at five sites within days after the injection. Accompanying the dye traces, analysis of the water chemistry was conducted. High levels of sodium, chlorides, and nitrates indicated that contamination from surface was impacting the cave

The Park acquired funding to initiate an intensive, multi-year water quality monitoring project to follow up on the work of Alexander and Davis. Twenty cave sites were sampled quarterly between October 1991 and July 1994. Half of the sites were located beneath the park's developed area, and the other half were located outside of the developed area. The sampling plan was designed to discover potential water quality impacts introduced by the Park's developed areas (*Nepstad 1997*).

The study discovered that Wind Cave's water quality was extremely variable. Levels of dissolved metals were relatively low in October of 1991 when sampling was initiated. During the course of the winter, levels of many metals increased significantly. Many sites contained dissolved lead in concentrations above 100 ppb, with some as high as 276 ppb. The high levels decreased during the spring of 1992. By July 1992, most metals were essentially absent. (*Nepstad and Wiles 1993*)

Davis *(1992)* performed preliminary studies to determine if the metals were from the soils or the cave. Due to the thin nature, or virtual absence of organic soil, the samples probably represented bedrock instead of soil. Samples of soil and associated bedrock from several sites above Wind Cave were placed into three-foot glass columns and rain water was passed through them. The study concluded that the water dissolved as much as 80 ppb of lead from its brief contact with Minnelusa soils and bedrock. Significant amounts of chromium and titanium also were detected. This indicated that the levels of metals seen in the cave water may have a natural origin derived from the bedrocks and soils.

To determine the source of Alexander's discovery of hydrocarbons in cave waters, the park began sampling extensively for hydrocarbons in 1991 and 1992. Sampling showed parking lot runoff was a mixture of hydrocarbons. Additionally, the composition changed based on the rain events. Twenty cave sites were sampled for benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds twice during 1991 and 1992 (*Nepstad 1997*). Toluene and the other BTEX compounds were absent from all sites. Polycyclic Aromatic Hydrocarbon (PAH) and volatile scans by the U.S. Environmental Protection Agency (EPA) did not find measurable quantities of specific hydrocarbons. However, Total Petroleum Hydrocarbon (TPH) tests showed that hydrocarbons from the parking lot likely were entering the cave. One cave site (Upper Minnehaha Falls) was sampled just prior to a rain event and shortly afterwards. At the site, TPH values increased from 50 parts per billion (ppb) prior to the rain event, to 560 ppb shortly afterwards (*Venezky 1994*).

In an attempt to better understand contamination from surface developments overlying the cave, the staff initiated a series of dye traces through portions of the vadose zone overlying the cave. A variety of cave locations with dripping or pooled water were monitored for up to five years following dye injection. Transit times to the cave varied from less than six hours to as much as 4.8 years. Despite a variety of positive results, there appears to be little correlation between transit time and lateral or vertical distance from the injection site. Data analysis produced traditional shaped dye recovery curves in some locations, albeit extended over hundreds and possibly even thousands of days after dye injection. The results showed that chemical or sewage spills in the vicinity of the dye injection sites could quickly enter multiple sites in the cave system and persist for years. Park management assumed that if dye can travel to the cave, then hydrocarbons also could do the same. These study conclusions were used to help secure funding for redesigning the parking lot. (*Nepstad 2015*)

During a 2002-03 USGS study, the potential influence of parking lot runoff on cave drip water was investigated. After three simulated rainfall events, samples were taken at the southern parking lot culvert and within the cave at a drip site known as Upper Minnehaha Falls. Samples were testing for BTEX compounds as well as other hydrocarbons. The cave samples had traces of acetone, total benzene, ethyl benzene, meta- and para- xylene, ortho-xylene, and styrene. The culvert samples had several BTEX compounds including toluene, benzene, and meta and para-xylene, as well as other hydrocarbons including chloroform, methyl isobutyl ketone, and acetone (*Heakin 2004*).

The parking lot was replaced in 2004 with a concrete surface and a drainage system designed to allow runoff water from the hillside above the parking lot to naturally drain into the canyon. Additionally, the drainage system diverted runoff from the parking lot into an oil and grease separation system, which then used a drainage system that simulated natural infiltration.

The Mixing Circle

The Mixing Circle was originally an area for mixing asphalt for road construction at the Park. No longer used for that purpose it has transitioned to an equipment and debris storage area for the Park. It is located in an intermittent drainage just upstream of known passages of Wind Cave. The drainage is usually dry, but it occasionally flows after heavy rains or snowmelt. The Mixing Circle is within the 500-year floodplain, and the 100-year floodplain. Any water within the drainage quickly infiltrates into the ground, likely traveling to the cave and groundwater.

In 1993, the park sampled soils in the vicinity of a former burn pile located at the Mixing Circle to find contamination. Large quantities of treated fence posts had been burned at the site for over 25 years. Due to limited funds, sampling included only copper, chromium, and arsenic. The results indicated contaminated soils with values of 427 mg/kg arsenic, 101 mg/kg chromium, and 235 mg/kg copper. (*Nepstad 1994b*)

In 1996, the park secured funding to further study the fence post burn site. The fence posts had been treated with pentachlorophenol (PCP), or with a copper-chromium-arsenic (CCA) mixture. It was thought that ash from the burned fence posts could have been the source of small quantities of PCP (up to 0.24 ppb) detected in 1994 at a cave site known as the Pile-Up, which is located nearly below the site. Fence post burning at the site was immediately terminated and funding for a study of the soils and groundwater was initiated. In fall 1996, the study found low measurable levels of PCP (<0.02 PPB) at the Pile Up. Following measurements of PCP values over time at this site (0.24 ppb in January 1994, 0.02 ppb in July 1994, and <0.02 ppb in November 1996) showed that terminating fence post burning likely reduced and eliminated PCP contamination of cave waters. The last posts were burned in the fall of 1993. By fall of 1996, PCP levels in the overlying soil were no longer measurable (*Nepstad 1997*).

Development and Land Use within Stream Watersheds

Stream Flow

Streamflow declines greatly affect wildlife, groundwater recharge, and cave geologic processes. Thirty private landowners upstream of the park along Beaver Creek have built dams to create small ponds. These dams reduce streamflow through the Park (*Ohms 2011a*). During times of low stream flow, the inflow into the ponds can be less than evaporation, meaning little to no water flows beyond the dam. In 2011, Hughes investigated the influence of the dams on the flow of Beaver Creek. The analysis showed evaporation from small dam reservoirs could reduce streamflow in Beaver Creek appreciably. Further study is required to more precisely quantify the impacts to Beaver Creek streamflow and groundwater recharge to the aquifers within the park (*Hughes 2011*).

Pringle Post and Pole

The Pringle Post and Pole is a 10 acre site along Beaver Creek at Pringle, South Dakota, about five miles upstream of the Park. Six acres of the site were used for wood treatment from the mid-1940's to the mid-1990's. Contaminants used the site could threaten the Park's water resources. State records indicate that the site's treatment activities initially involved mixing pentachlorophenol (PCP) with diesel fuel in unlined pits dug in the soil. Later, tanks were used where the wood products were dipped and treated with the PCP solution. Most recent treatments used a pressure treatment vessel where wood products were treated with chromated copper arsenate (CCA) (*Heakin and Ohms 2005*).

The U.S. EPA listed the site on the Comprehensive Environmental Response, Compensation, and Liability Information System in July 1991(*U.S. Environmental Protection Agency, 2004*). Ecology and Environment, Inc. for the EPA conducted site investigations in 1992 and 1994. The results of the investigation were documented in two unpublished reports (*Ecology and Environment, Inc.1992, 1994*). The study found soils contaminated with PCP, polycyclic aromatic hydrocarbons, dioxins, furans, arsenic, chromium, copper, and zinc. The South Dakota Department of Natural Resources and of Agriculture inspected the site prior to 1992 and documented areas of soil contamination and observed releases of CCA.

The site was visited again in 2001 by URS Operating Services, Inc., under EPA contract. URS collected samples of soil and water to evaluate the site for the EPA's Hazard Ranking System criteria. The investigation documented elevated levels of dioxins and furans in water and sediment samples collected from Beaver Creek downstream from the site (*URS Operating Services, Inc., 2002*). The USGS conducted a water-quality assessment of the surface-water resources in Wind Cave National Park between 2002 and 2003, and found that concentrations of chromium, nickel, and iron were higher in Beaver Creek than in other streams within the park (*Heakin, 2004*).

Although operations at the Pringle Post and Pole Site ended in the 1990s, investigations sponsored by the EPA during 2002 indicated that elevated concentrations of some contaminants were present at the site and at downstream locations on Beaver Creek 12 years after operations ended. URS Operating Services, Inc. (2002) documented concentrations of PCP found in soils from the Pringle Post and Pole site that ranged from 55 to 2,300 times background levels and exceed the EPA's Superfund Chemical Data Matrix Soil Pathway Cancer Risk Screening Concentrations. Dioxins and furans also were found at elevated concentrations on the site with the highest concentrations found in soils near the grated drain that carried site runoff water beneath the highway and into the Beaver Creek drainage. Additionally, various hazardous and toxic chemicals were drained from the Pringle Post and Pole site and to Beaver Creek drainage during periods of overland runoff. Since 1990, the USGS operated a stream flow gage on Beaver Creek inside the park. During the gage's period of record, stream flows of a magnitude sufficient for transporting contaminated sediments for substantial distances downstream have been recorded. Therefore, it is likely that contamination from the Pringle Post and Pole Site could threaten the aquatic environment in Beaver Creek, the cave, and the park's drinking-water supply. (*Heakin and Ohms 2005*)

Mining

There are sixty documented mines within the Beaver Creek Drainage and two in the Cold Spring Creek drainage (*Ohms 2011*). The mined minerals include mica, feldspar, beryllium, tantalum, lithium, niobium, and crushed stone. Currently, there is sparse active mining in the area but future mining interests are possible. Impacts to water resources in the Park from mining activities or mine runoff have not been studied or documented. Additionally, no documented reclamation work has been conducted at any mine site.

Development

Private land development rates in the Beaver Creek watershed have accelerated. There are currently 124 private residents within the drainage basin, and the number is increasing yearly (*Ohms 2011*). The region has several new housing developments. With each new house there is an additional septic system and an increase in the water demand. It is likely that additional septic systems and water demand will increase the existing influences on the Park's water resources.

Conclusions and Recommendations

World renowned water resources reside in Wind Cave National Park. These resources require persistent study, management, and protection. We are just beginning to understand the connections between these resources and their significant influences.

The research completed to date indicates measurable impacts to surface and groundwater resources from development outside and inside the Park. The cave system is sensitive to contaminants from the surface during both short and long timespans. Research and monitoring efforts must continue well into the future to ensure that the Park fully understands its resources and can continue to increasingly improve its management practices. Future studies are especially important during changes such as land development, groundwater withdrawals, and climate change that have a direct impact and potentially threaten these critical water resources.

During Stone's *(2011)* two-year mercury sampling he found an increasing tread of mercury within our precipitation. Further monitoring is warranted to see if the mercury levels are continuing to rise.

There is an increasing trend of pesticide use within the Park. Utmost caution needs to be exercised to ensure the cave and water resources are not impacted. Research has proven the vulnerability of the cave and groundwater to surface contaminants (*Alexander 1989, Heakin 2004, Nepstad 1993, 1997, and 2015, Venezky 1994)*. This lesson must not be forgotten. A no-spray zone should be established above the most sensitive areas in Wind Cave Canyon.

The Park's parking lot and sewer lines have been reconstructed to protect water resources. However, no follow-up testing has been conducted to determine if the mitigations have actually worked. A proposed project has been submitted to the NPS/USGS Water Quality Partnership funding source and currently is under consideration for funding.

It has been well documented that the drainages above the cave are the most vulnerable areas to infiltrating water carrying contaminates into the cave and groundwater (*Alexander 1989, Heakin 2004, Nepstad 1993, 1997, and 2015, Venezky 1994)*. Unfortunately, this is where most of the Park's infrastructure (campground, picnic area, Visitor Center, housing, maintenance area, and the Mixing Circle) are located. It is vital that the Park protects the cave and water resources as its top priority when managing activities within this area.

Heakin *(2004)* found that water quality in Beaver Creek is being impacted from activities upstream of the park, and Hughes *(2011)* suggests that impoundments may be impacting water quantity. Further work is needed to determine the extent and sources so that cooperative measures with landowners and agencies can reduce or mitigate the impacts.

Murray, et. al. *(2015)* has indicated that the Park streams at times may have levels of E coli near impairment levels. Further work is needed to determine the extent and sources of the bacteria.

"*We realize the value of water only when the well runs dry*" Ben Franklin

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